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EDITORIAL

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Special Section:

Mining and Planetary Health

Key Points:

- Mining is necessary for providing wealth, goods, energy, and building materials and underpinning social and industrial development
- Mining can release contaminants that can impact on the health of humans, ecosystems, and Earth surface environments
- *GeoHealth* is leading a special collection of papers focusing on mining and planetary health, to which submissions are invited

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Mining and Planetary Health: A *GeoHealth*-Led Special Collection

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Abstract Mining is a vital part of the global economy, but unmanaged releases of mine wastes can affect the health of humans, ecosystems, water, soil and Earth surface environments (e.g., rivers and estuaries). New technological developments and multidisciplinary collaborations are leading to new insights into the relationship between mining and the health of the Earth. In recognition of the importance of this topic, *GeoHealth* is leading in the creation of a special collection of papers on the theme of Mining and Planetary Health, to summarize the current state of knowledge, outline topics for urgent action and further research, and highlight positive efforts in environmental and health protection. Submissions are invited from researchers investigating the impacts of mining at the intersection of the Earth and environmental sciences and human, ecosystem, and planetary health.

Plain Language Summary *GeoHealth* invites submissions on mining and planetary health, in recognition of the importance of understanding the impacts of mining on human, ecosystem, and Earth surface environmental health.

1. Introduction

A rapid response assessment report published by the United Nations Environment Programme and GRID-Arenda in 2017, entitled *Mine tailings storage: Safety is no accident*, stated that “safer, cleaner and less wasteful extraction and production is paramount to ensuring resource availability, but also community well-being and ecosystem resilience” (Roche et al., 2017). The report was published in the wake of the largest mine tailings dam accident in history to date. On 5 November 2015, the Samarco Mineração S. A Fundão tailings dam in Brazil failed, releasing ~33 million m³ of tailings that flowed 650 km downstream along the Rio Doce to the Atlantic Ocean, killing 19 people, displacing hundreds more, contaminating potable water supplies, decimating fish populations, and blanketing the area with red tailings mud (Grupo da Força-Tarefa, 2016; Samarco, 2015). The failure illustrated the severe effects that the dispersal of mine waste can have on the quality of water and soil, on the health of ecosystems and humans, and on social disruption and unfinished and unresolved outcomes for impacted communities. The United Nations report highlighted these effects and described industry efforts to reduce their severity, adding to a growing body of literature calling for action and encouraging research on mine wastes (e.g., Hudson-Edwards, 2016; Santini & Gagen, 2018).

Mining for metals, coal, oil sands, industrial minerals, gemstones, and rocks has been carried out since the dawn of civilization, providing wealth, goods, energy, and building materials and underpinning social and industrial development. Contemporary mining has similar benefits and also contributes to economic growth with extraction of new types of commodities such as critical raw materials (e.g., Co, Li, rare earth elements, and W) used for modern technologies including solar energy, batteries, and computer devices. However, past and present mining continues to have an ongoing impact on the health of humans and ecosystems and on natural water, sedimentary, and atmospheric systems through large inputs of potentially toxic and radioactive elements and particulates, at very high or low pH and high salinity (Hudson-Edwards et al., 2011; Landrigan et al., 2018). The future of mining will involve increased extraction of traditional and new types of materials (Alonso et al., 2012) whose deposits have lower grades as those with high grades are exhausted (Mudd, 2010). These lower-grade deposits consequently have higher waste-to-ore ratios. In many parts of the world, increased environmental awareness is driving novel and efficient remediation and management of mine wastes. Community action is also helping to support sustainable mining practices (Zou & Lin, 2017). The importance of these activities is emphasized by the large number of current research projects in diverse disciplines and outputs and global initiatives for future mining and environmental and health protection (e.g.,

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United Nations Initiative on artisanal and small-scale gold mining, <http://www.unep.org/chemicalsandwaste/global-mercury-partnership/reducing-mercury-artisanal-and-small-scale-gold-mining-asgm/meetings-7>; Initiative for Responsible Mining Assurance, <http://www.responsiblemining.net/>; WHO International Programme on Chemical Safety, <http://www.who.int/ipcs/publications/ulab/en/>.

2. Mining and Human, Ecosystem, Water, Soil, River, and Atmospheric Health

The extraction and processing of ores and wide distribution of mine wastes enriched in As, Hg, Pb, Si, U, coal, and other elements and compounds has impacted on human health over thousands of years (e.g., Dong et al., 2015; Plumlee & Morman, 2011). Recognition of these impacts has led to better health and safety and monitoring program being implemented in many operating mines. This is not the case everywhere, however, and many contemporary and historic mine wastes remain unmanaged, releasing contaminated dust and water (Martin et al., 2016). Likewise, ecosystems can suffer negative health consequences due to high burdens of toxic elements and compounds (e.g., poisoning of cattle due to remobilization of historic Pb-contaminated alluvium; Foulds et al., 2014), but there are reported cases of plants and biota adapting to the new conditions imposed by mining (worms adapting to Pb-bearing waste in Wales, UK; Andre et al., 2010).

Other major environmental impacts of mining include contamination of water, soil, and rivers and offsite export of dust. For example, mining involves the use of substantial quantities of water, and this impacts on resources in some parts of the world due to overuse, lack of supply, and climatic factors (Mudd, 2008). Water bodies are also contaminated by mining discharges and interactions with mine wastes, forming acid, neutral, and basic mine drainage (Nordstrom, 2011). However, these negative factors are being balanced by positive developments as new technologies for water treatment and resource recovery from wastes emerge (Kefeni et al., 2017). Mining- and smelting-related contaminants have also impacted on the quality of soil and sediments. Such contaminants are added to soils and sediments through direct discharge and through fluvial and atmospheric deposition, posing risks to ecosystem and agricultural health (Zhao et al., 2012). Global food chains can be affected through uptake of these contaminants directly by soil organisms or indirectly through eating crops grown on the soils and sediments (Andrew et al., 2019; Miller et al., 2004; Reichelt-Brushett et al., 2017).

Mining has had significant impacts on fluvial morphodynamics and biogeochemistry because mine wastes have been and still are discharged to river systems (e.g., Ajkwa River, Indonesia; Alonzo et al., 2016). *Acute* contamination events (known also as *active transformations*; Lewin & Macklin, 1987) such as tailings dam spills add huge amounts of sediment and water to rivers, creating new landforms (e.g., sandbars) and causing channel change. Human and ecosystem health can be severely affected through oxygen depletion and toxic *shock* (e.g., 4,000 human deaths following the 1626 San Ildefonso dam failure, in Potosí, Kossoff et al., 2014; killing of all fish and shellfish in Río Guadamar following the 1998 Aznalcóllar tailings dam failure, in Spain, Grimalt et al., 1999). By contrast, *chronic* events (or *passive dispersal*; Lewin & Macklin, 1987) such as continual effluent discharge or remobilization of contaminated alluvium affect sedimentation rates and contaminate the river sediment and water. The geomorphological effects are not as dramatic as those resulting from the acute events, but the addition of sediment can still cause diversion of watercourses and creation of new landforms, especially in high-flow regimes (e.g., River Nent, NE England, Lewin & Macklin, 1987). Chronic contamination can lead to toxic effects in plants and animals (Ashraf et al., 2011) or the development of metal- or metalloid-resistant species (e.g., Paul et al., 2017). Fortunately, riverine discharge of mine waste is declining due to community dissent, government regulations, and industry-led initiatives.

Dusts are generated from mining and processing operations and from the eolian weathering of mine wastes. These dusts add to the particulate load of the atmosphere and thus can affect climate. They are also often enriched in toxic contaminants that can affect atmospheric biogeochemical cycles and human health (Csavina et al., 2012; Ramirez-Andreotta et al., 2013).

3. The Future of Mining and Planetary Health

Mining is still as relevant in today's society as it has been in the past, contributing wealth (directly or indirectly, up to 20–30% of gross domestic product in some countries; World Bank & International Finance Corporation, 2002; Hydralok, 2018), infrastructure, goods, and scientific knowledge. The future of mining is therefore vital, but ideally it should be conducted in a sustainable way. Many modern mining activities

have low environmental impacts, as robust efforts are made to limit liquid waste discharges, control dust emanation, and reclaim mined land and tailings and waste rock piles (Boerchers et al., 2016). However, most of the health benefits are in developed nations, while in low- and middle-income countries the environmental and social impacts of mining are similar to those in the past, with uncontrolled discharge of solid and liquid wastes, little to no reclamation, and little regard for human health or other social impacts (Bustamante et al., 2016). Legacy mining impacts will also need to be properly managed to protect environmental systems and human and ecosystem health. One possible way forward is the use of environmental pollution insurance, which financially protects businesses against the liability associated with events related to their activities that can harm the environment (e.g., releases of pollutants; Environmental Protection Agency, 2017).

An analysis of the incidence of accidents such as large tailings dam failures, which could lead to loss of life or other significant impacts, by Bowker and Chambers (2015) has shown that these accidents are increasing due to processing of low-grade ores with high waste:ore ratios and building large dams of more than $5 \times 10^6 \text{ m}^3$ capacity. Increases in the global burden of mine waste and in mine waste accidents (e.g., August 2015 discharge of $13.6 \times 10^6 \text{ L}$ of acidic mine wastewater to the Animas River in Colorado) highlight the urgency to review advances in interdisciplinary research on mining and planetary health, identify knowledge gaps, and develop global biogeochemical cycles for mine wastes, which in turn could be used to improve global pollution regulations and protocols.

A multidisciplinary approach, involving geoscientists, human health researchers, ecologists, microbiologists, geographers, chemists, social scientists, environmental futures and sustainability scientists, and workers in many other disciplines, is required to fully evaluate the relationship between mining and planetary health. Over the past few decades, advances in modeling using novel geochemical, geospatial, mathematical, and remote sensing technologies have aided the understanding and prediction of the impacts of mining on Earth system processes. Examples include the global mapping of mine waste using satellite imagery and unmanned aerial vehicles; quantification of solid mine waste transfer by rivers (Macklin et al., 2006); determination of microbe-metal mine waste interactions (Gadd, 2010) and of the molecular-scale stability of mine waste minerals (Acero & Hudson-Edwards, 2018); and determination of geochemical modeling codes (PHREEQC; Parkhurst & Appelo, 2013) to model biogeochemical reactions occurring in mine wastes and of numerical models to track and predict mine waste dust transport and deposition (Coulthard & Macklin, 2003). These methods can in turn be used to evaluate the associations between mining and planetary health.

4. A GeoHealth-Led Collection of Papers on Mining and Planetary Health

In recognition of the importance of this topic, the American Geophysical Union has approved the creation of a special collection of papers on the theme of Mining and Planetary Health, to be led by *GeoHealth*. The aims of the Mining and Planetary Health Collection are to summarize state of current knowledge of mining and planetary health, highlight areas of particular concern that require urgent action and further research, and report success stories that hold promise for contemporary and future environmental protection. The collection will provide information that will contribute to improving the quality of life and Earth surface environments (e.g., identifying global hot spots of contaminated mine waste storage and transfer that can be remediated or managed to improve ecosystem, human, soil, and water health) and knowledge transfer (e.g., providing a better understanding of the global impacts of mining on water, soil, air quality, and health).

We welcome submissions relating to the topics discussed in this editorial and others including, but not limited to, the following topics: (i) chronic and acute effects of mining on human and ecosystem health; (ii) the impacts of mining on water, soil, and air quality and on the physical, chemical, and biological processes related to water management, hydrology, and resources; (iii) impacts of mining on fluvial, eolian, terrestrial, and coastal environments and on Earth surface processes (weathering and pedogenesis); (iv) mining-related dust characterization, sources, sinks, fluxes, modeling, and future trends; (v) modeling of the relationships between mining and planetary health at a range of temporal and physical scales; and (vi) future impacts of mining on water, air, food, energy, hazards, climate and weather, ecosystem and human health, and demographics.

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